Mausam, (1979), 30, 2 & 3, 305-312

550.341 (545)

Recent seismic activity in Delhi and neighbourhood

V. P. KAMBLE and H. M. CHAUDHURY

India Meteorological Department, New Delhi

ABSTRACT. In order to assess the seismic status of existing faults burried under thick alluvial deposits in the plains around Delhi, a total of 937 recorded shocks have been analysed. The spatial and temporal distibutions of earthquakes and strain release patterns have been discussed with reference to the positions and trends of the existing fault patterns. The value of slope coefficient *b* was found to decrease before and increase just aftei the major events.

1. Introduction

Many geological studies in the last decade have indicated that there are a number of hidden faults in the thick alluvial deposits of Indo-Gangetic plains. While assessing the significance of the Moradabad fault in the Indo-Gangetic basin Krishnaswamy (1962) concluded that due to lack of data, the geomorphological approach to the problem of recent activity along the fault has not been successful. A recourse to seismological studies by adequate instrumentation in the area seems unavoidable.

During the years 1963-64 a large number of tremors were experienced around Sonepat. This gave an apportunity for a detailed study of seismicity of this area.

2. Observational network and data collection

In order to study the earthquakes which occurred around Delhi-Sonepat, mobile seismological observatories were started by the India Meteorological Department at a few places (Fig. 2). Of these, the observatory at Ridge, Delhi is equipped with the worldwide standardised seismograph system. In addition, a two component Wood-Anderson seismograph is operating at this observatory for determining the magnitudes of the shocks. The other observatories in the network are equipped with sensitive electromagnetic seismographs. The details of the instruments and their constants are given in Table 1. A large amount of data has thus been collected over a period of ten years from 1964.

3. Determination of earthquake parameters

Epicentres and focal depths of all shocks detected were determined using the *P*-wave velocity of 5.70 km/sec and that of *S*-wave as 3.45 km/sec. These velocities which are different from those used in J-B Travel time tables were obtained from a few well recorded earthquakes which occurred earlier. A record of one typical event is shown in Fig. 1. The epicentres were determined correct to $\pm$ 1 km and focal depths to $\pm$ 2 km. The bigger events were assigned magnitudes from Wood-Anderson records. Magnitudes of smaller events which were not recorded in the Wood-Anderson seismograph were calculated from the maximum amplitude in the *S*-group as recorded on the standard short period system at Delhi. The peak to peak amplitude was reduced to ground amplitude in microns and magnitude was calculated using a nomogram (Richter 1935). In order to bring these magnitudes to common base, magnitudes of 100 shocks which were recorded in both instruments were compared. The difference of magnitudes ($M_L - M_0$) was plotted against M_0 and the points were fitted to a straight line. This calibration curve was used to correct the magnitudes of smaller events. A total of 937 shocks recorded has been used in the present study.

4. Seismic history and prominent tectonic features in the area

The study of the historical data shows that many damaging earthquakes have occurred near Delhi. A list of notable events is given in Table 2. In the year 1720, a shock of 6.5 magnitude with its epicentre near Delhi, was reported to have caused heavy damage to houses. According to Oldham (1883) the earthquake of 1 September 1803 was very violent at Muthra (Mathura). This shock destroyed principal mosques and was reported felt at Calcutta, Kumaon, upper valleys of Ganges etc. However, these appear to be two separate shocks. The other shock had its epicentre between Delhi and Simla and two to three hundred people were killed at Barahal. The earthquake of 1842, having its epicentre near Mathura was not so violent.

The earthquake of 10 October 1956 (Mag. 6.7) was reported to have been felt in a wide area. Twenty three persons were killed in Bulandshar district. Another major shock of magnitude 6.0 occurred in this area during the year 1960. Many

TABLE 1

Location of stations and instrumental constants

Station	Co-ordinates		Instrumen s	Magnification			T_o (sec)	Tg (sec)
	Lat. (°N)	Long. (°E)		Z	N	E		
Rohtak	28° 54′	76° 36′	E.M.	3,500	3,500	..	1·6	1·6
Sonepat	28° 59′	77° 00′	E.M.	4,300	4,300	..	1·6	1·6
Meerut	28° 55′	77° 40′	E.M.	4,800	3,600	..	1·6	1·6
Sohna	28° 15′	77° 05′	E.M.	100,000	..	..	1·5	0·5
Delhi	28′ 41	77° 13′	Benioff S.P.	50,000	50,000	50,000	1·0	0·75
			Sprengnether L.P.	1,5000	1,5000	1,500	15·0	100
			W.A.	..	1,000	1,000	0·8	..

TABLE 2

List of major historical earthquakes in Delhi region

Serial No.	Date	Epicentre	Magnitude	Description
1	15-7-1720	Delhi	6·5	A dreadful earthquake in which walls of a fortress were damaged. Many houses were destroyed.
2	1-9-1803	Mathura	6·5	A very violent shock which destroyed, principle mosques. Felt at Calcutta, Kumaon, Upper Valleys of Ganges. Caused intensive fissures in fields through which water rose with considerable violence near Mathura.
3	16-1-1842	Near Mathura		Felt extensively in Uttar Pradesh. Soldier's huts were damaged at Sultanpur.
4	14-1-1934	29·0°N-75·5°E	5	
5	10-10-1956	28·15°N-77·67°E	6·7	Felt in a wide area. 23 persons killed in Bulandshar.
6	27-8-1960	28·2°N-77·4°E	6·0	Many houses damaged at Gurgaon. Fifty persons hurt in Delhi.

houses were reported damaged at Gurgaon and fifty persons were hurt in Delhi.

The existing fault patterns interpreted from geological studies (Mehta *et. al* 1970) are also shown in Fig. 2. The Sohna fault, Aravali fault and Moradabad fault are the prominent tectonic features in this area. There are several other parallel faults inferred from geomorphological studies. They have been shown as XX, YY, ZZ etc. Mehta *et al*. (1970) postulated a tear fault lying at an uncertain position and with an unknown trend in the Sohna valley. The exact position of this fault known as Sohna fault could not be determined due to the deep alluvial deposits. The fault trending ENE and WSW (XX) is parallel to Moradabad fault. The fault (ZZ) intersects the Sohna fault towards the south of Delhi.

5. Spatial distribution of epicentres

Fig. 2 shows the distribution of earthquake epicentres in the area. It is interesting to note that there are three distinct areas A, B and C where concentration of epicentres has taken place. The Area (A) west of Delhi is near the junction of Aravali and Sohna faults indicating movement along these faults. The epicentres in this group, however, reveal a N-NE trend parallel to the inferred fault ZZ beyond the Sohna fault. However the depth of the earthquakes discussed later in the paper do not indicate assocation with this fault. The other cluster of epicentres is near Sonepat town (area-B). The trending of earthquakes in this cluster is NE-SW indicating the possible extension of Aravali fault towards Sonepat. The largest cluster of epicentres is in the

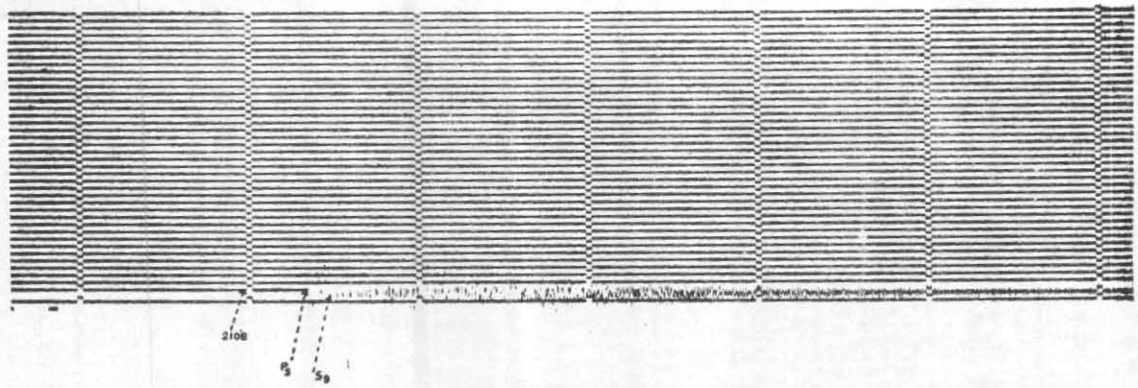

Fig. 1- Earthquake of 20 February 1974 recorded by Ridge Seismological Observatory, Delhi

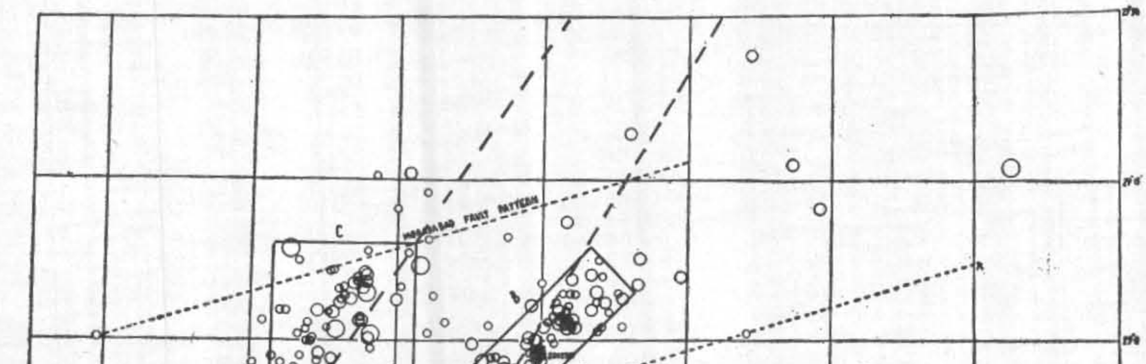

Fig. 2. Map showing the spatial distribution of earthquake epicentres, location of observatories and existing fault patterns

area-C near Rohtak. This activity may be due to continued movements on the fault XX and extension of fault YY trending NE-SW. The concentration of epicentres is more at the junction of different faults.

6. Magnitude frequency

The value of slope coefficient b in the magnitude-frequency relation was calculated using the well known equation (Aki 1965) :

$$b = \frac{\log e}{\overline{M} - M_0}$$

$$\overline{M} = \sum_{i=1}^{N} \frac{M_i}{N}$$

where $\overline{M}$ is the mean magnitude of the group of earthquakes, M_0 is the smallest magnitude and N is the number of events greater than M_0. For calculating the b value the earthquakes were grouped into a population of 25 starting with the occurrence of a comparatively stronger event. The value of b was plotted against the mean time for the group (Fig. 3). From all the sequences it was seen that the value of b is low before the main event but shows a rather sharp rise just after that. In the beginning of a particular sequence, it decreases generally between the two major events.

The coefficient b was also determind graphically for intervals of two years (Fig. 4) and for the entire period of ten years. The values thus computed are shown in Table 3 along with those of the intercept a. It may be seen that the value of b increased till 1969 and then decreased afterwards. It was maximum during the active years 1968-69 and minimum during 1972-73.

The b value fluctuated from 0.76 to 0.97 whereas for the entire period from 64-73 the value of 0·92 was obtained. The variation of b value computed by the method described earlier is from 0·41 to 0·87. While the maximum b values in the sequence obtained by the two methods compare well, there is divergence in its lower limit. This could be due to the different groupings used in the two methods. The earthquake recurrence curve was plotted for the area of 10,000 square km around Delhi and is shown in Fig. 5. The frequency of occurrence of 4-M shock, calculated from this curve, was found to be 1 shock per year which is in good agreement with the observed frequency.

7. Yearly frequency

Fig. 6 shows the plot of number of events per year. The number of shocks recorded during the year 1964 is less as the data was available for a period of 6 months only. There is a marked increase in the activity during the years 1968 to 1970 and it is maximum in the year 1969. There is again a spurt in the activity during the years 1972 and '73. It is observed that a spurt in the seismic activity takes place when one or two higher magnitude shocks occur in the sequence showing the effect of aftershock activity.

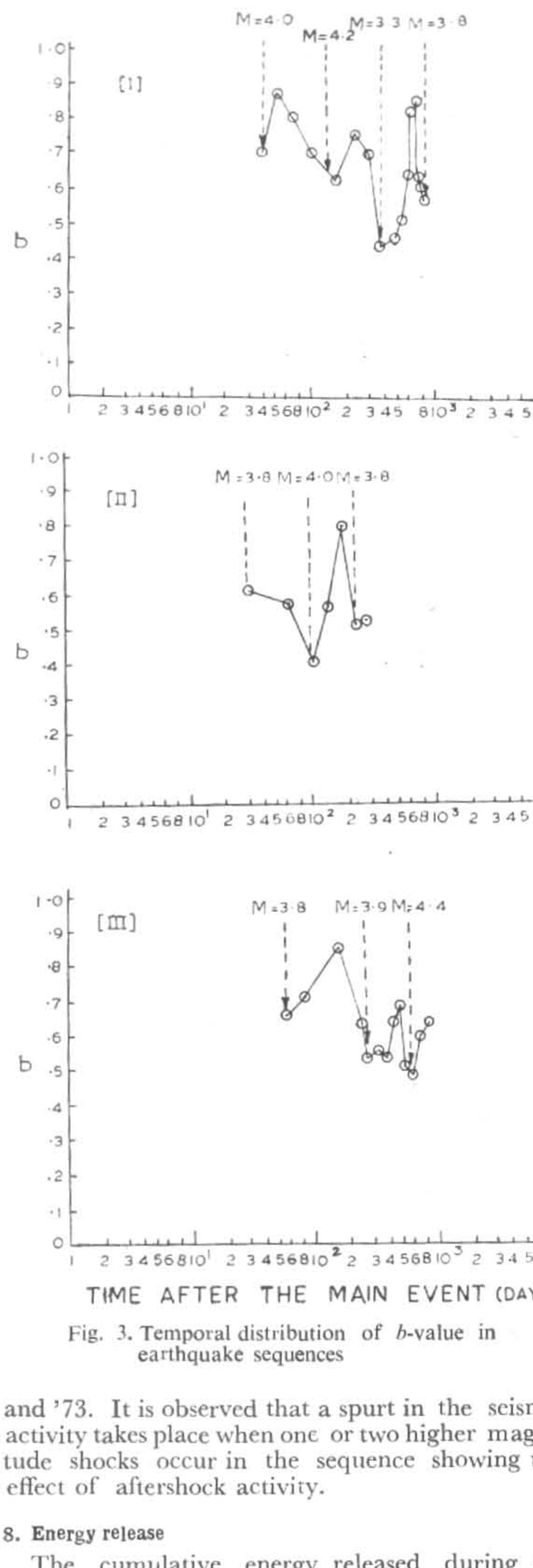

Fig. 3. Temporal distribution of b-value in earthquake sequences

8. Energy release

The cumulative energy released during the entire period from 1964-73 is shown in Fig. 7. It may be seen that the period of quiescence is followed by a period of increased seismic activity

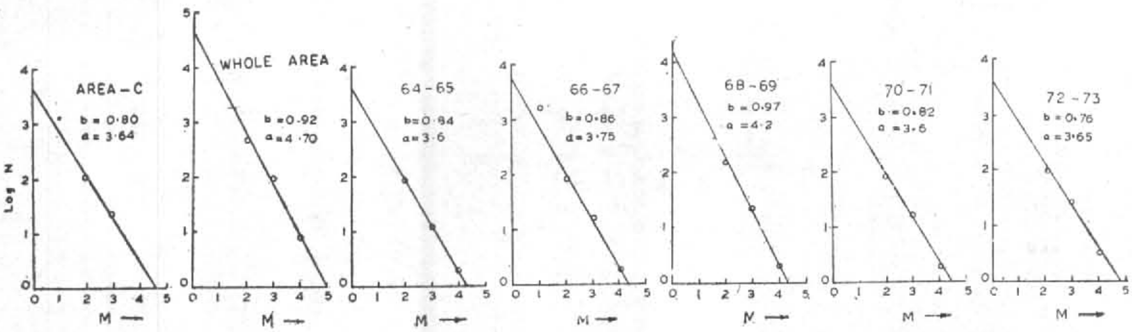

Fig. 4.Variation of slope coefficient

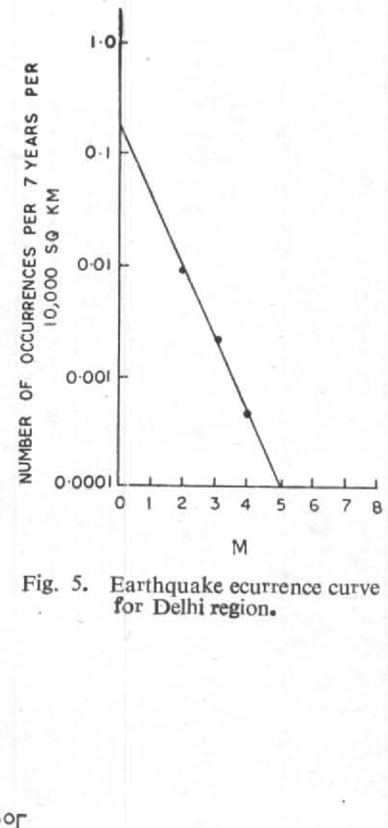

Fig. 5. Earthquake ecurrence curve for Delhi region.

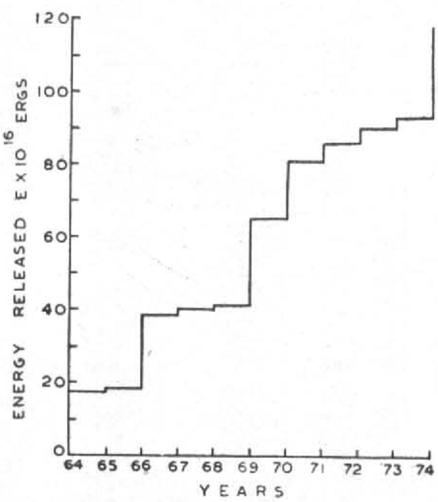

Fig. 7. Cumulative energy release.

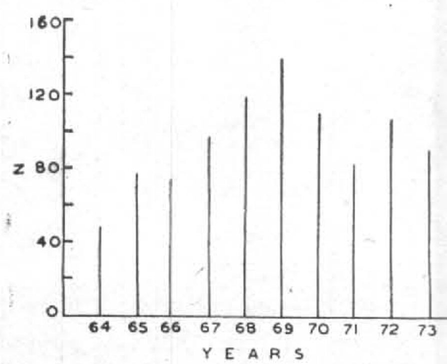

Fig 6. Yearly frequency of earthquakes

TABLE 3

Variation of b-values

Period (Years)	Intercept (a)	Slope coefficient (b)
1964-65	3·60	0·84
1966-67	3·75	0·86
1968-69	4·20	0·97
1970-71	3·59	0·82
1972-73	3.55	0·76
1974-75	4·70	0·92

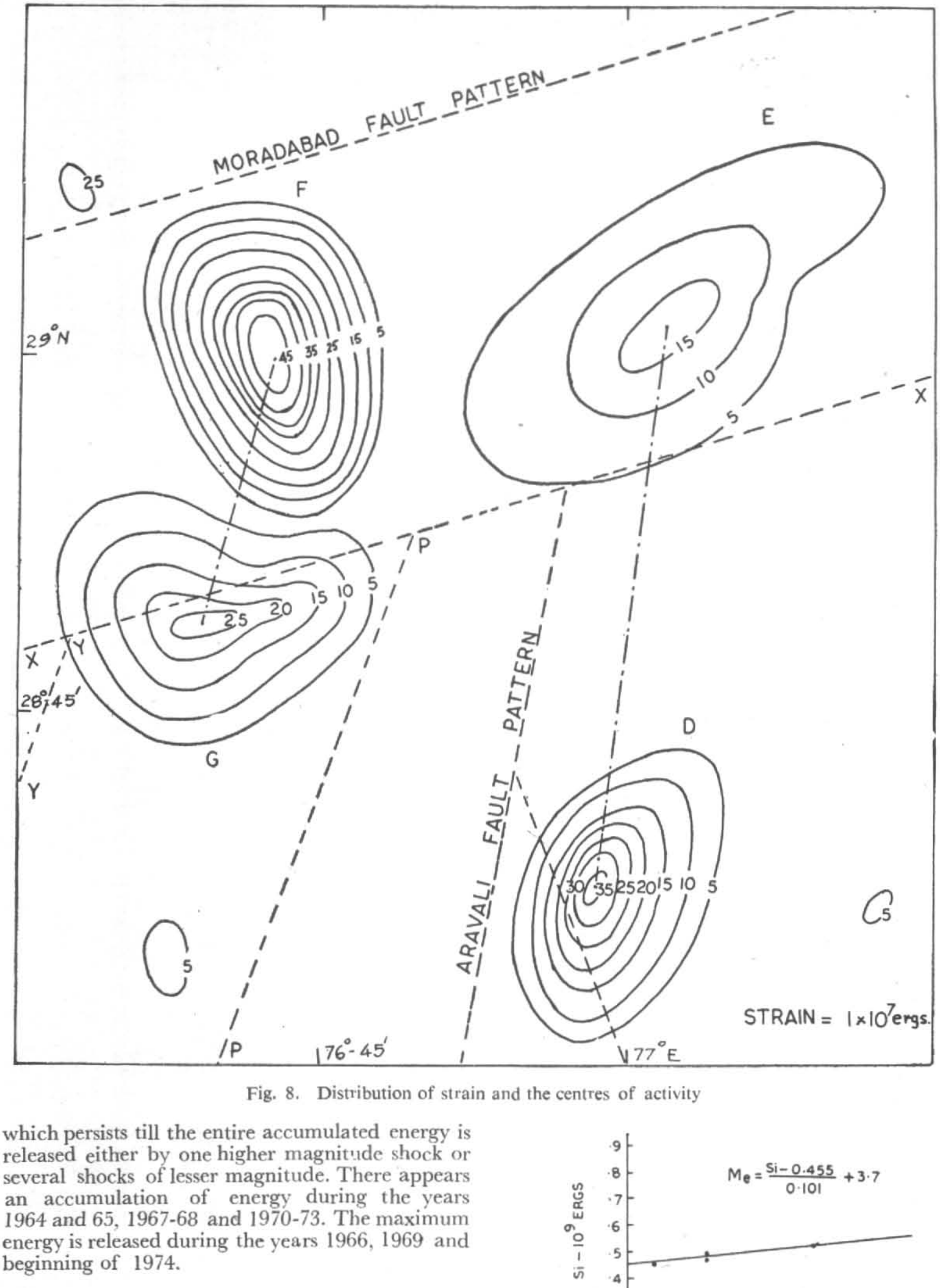

Fig. 8. Distribution of strain and the centres of activity

which persists till the entire accumulated energy is released either by one higher magnitude shock or several shocks of lesser magnitude. There appears an accumulation of energy during the years 1964 and 65, 1967-68 and 1970-73. The maximum energy is released during the years 1966, 1969 and beginning of 1974.

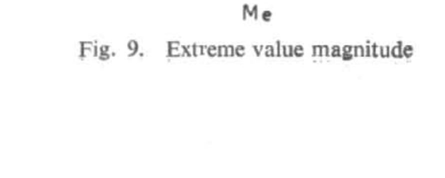

Fig. 9. Extreme value magnitude

9. Strain release

The strain released over the period of ten years is shown in Fig. 8. For the purpose of averaging

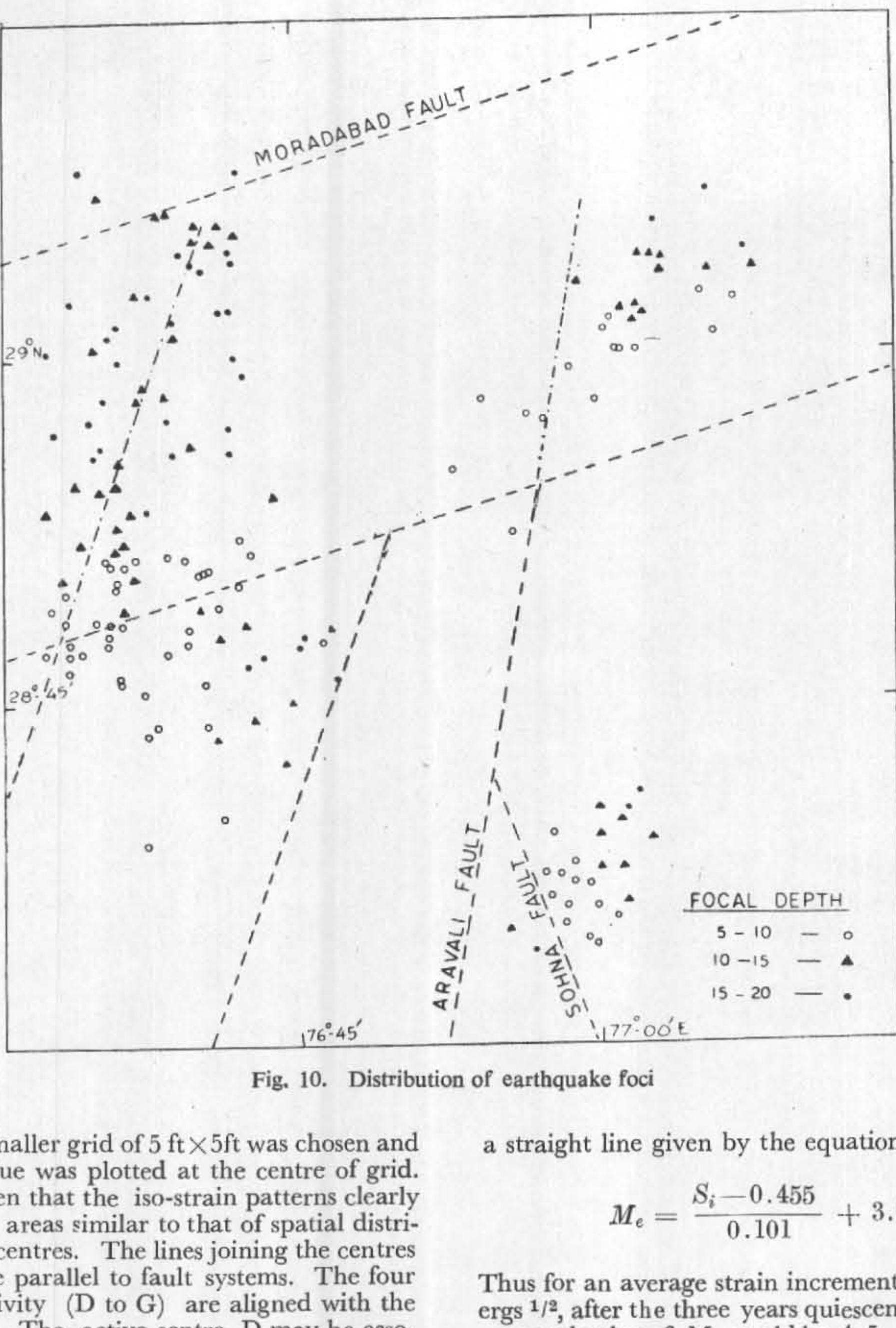

Fig. 10. Distribution of earthquake foci

the strain a smaller grid of 5 ft × 5ft was chosen and the mean value was plotted at the centre of grid. It may be seen that the iso-strain patterns clearly define active areas similar to that of spatial distribution of epicentres. The lines joining the centres of activity are parallel to fault systems. The four centres of activity (D to G) are aligned with the fault systems. The active centre D may be associated with movements on Sohna fault. But it is more likely that this centre could be associated with the junction of Aravalli fault and Sohna fault. From the figure it may also be seen that the centre G could be associated with the junction of two faults XX and YY. The other centres F and E may be related with movements on the extension of fault YY and Aravali fault respectively. The average period of quiescence of seismic activity in this region is three years. The contribution to strain rebound increment is mostly due to a shock of higher magnitude. Therefore the strain increment S_i was plotted against the extreme magnitude value M_e (Fig. 9). The curve was fitted to a straight line given by the equation:

$$M_e = \frac{S_i - 0.455}{0.101} + 3.7$$

Thus for an average strain increment of 5.35×10^8 ergs $^{1/2}$, after the three years quiescence period, the expected value of M_e would be 4.5.

10. Distribution of foci

The focal depths were plotted in space to find the trend in crustal dipping. Since some scattering was noticed, smoothing of focal depths was necessary to obtain a clear picture. The averaged focal depths were plotted in Fig. 10. In the area-A shallow focus shocks are concentrated along the Sohna fault. The foci of deeper shocks lay further away from the trace of the fault towards NE indicating a possible dipping in that direction. In the area-B the trend is N-NE and may be associated with the extension of Aravali fault. In the area C there are two trends. The crustal layer north of parallel fault XX appears to be dipping towards the NE and that south of it is dipping towards east and may be associated with the fault YY and its extension.

11. Discussions

During the period from 1963-65 a swarm type activity was observed near Sonepat. A shock of magnitude-4 occurred on 2 Oct 1964 (20*h* 09*m* 31.7 *s*) with its epicentre barely 4 km away from Sonepat. More than 25 shocks were reported felt at Sonepat subsequently. The actual figure might be more as the felt reports were not available for large number of shocks. Hukku (1966) concluded that this swarm was related to tectonic activity along a tear fault connected in the south with the nearly N-S trending fault as interpreted at Sohna and in the north with the Yamuna tear or with a branch fault thereof in the Himalayan foot-hills. Srivastava and Somayajulu (1966) suggested that the northern extension of the Peninsular shield at Delhi is cut up by block faults. They designated a N-S trending fault as Sonepat Delhi-Sohna fault. From the spatial distribution of epicentres and the pattern of strain release the activity near Sonepat appears to have been associated with a possible extension of Aravali fault.

The activity in area A seems to be related to the junction of Aravali and Sohna faults near latitude 28° 35′. The alignment of shocks between the area A and B and strain release pattern suggest a slight shift of the trace of Aravali fault towards east by few kilometres. However, this observation needs further investigations based on actual field studies.

The activity in the area C is divided in two groups. The activity towards north and south of Rohtak seems to be associated with the possible extension of fault YY. This may also be seen from the spatial distribution of epicentres and the strain release patterns.

Gibowicz (1973) in studying the earthquake sequences in New Zealnd observed that the value of *b* decreased regularly during the activity from 1·2 at the begining to 0.6 by the final stage. The three sequences studied by the authors also indicated that the value of slope coefficient *b* decreased before and increased just after a bigger event. In the present study it decreased from a value of 0·87 to 0·4 with one or two maxima in the sequence in agreement with the observations of Gibowicz. It seems that the variation of slope coefficent in a sequence has a regional characteristic. The values of *b* computed graphically for block of two years varied from 0·76 to 0.97 (Table 3). Tandon and Chatterjee (1968) obtained the value of 0·92 for Delhi region and 0·97 for Sonepat region. The value of 0·92 computed for the entire period from 1964-73 and that of 0.97 for 1968-69 are in good agreement with their results. Chaudhury *et al.* (1970) gave a value of 0·88 for Delhi region which agrees well with the values of block of year 1964-65, 1966-67 and 1970-71.

12. Conclusions

The earthquake activity in Delhi and neighbourhood is related to tectonic activity along the faults present in this area.

The spatial distribution of earthquakes and strain release patterns roughly indicate the extensions and trends of faults burried under thick alluvial deposits.

The value of *b* in a sequence decreases before the major shock and increases immediately after that.

There is a gradual decrease in *b* value till the occurrence of another major shock, the threshold magnitude being of the order of four.

References

Aki, K., 1965, *Bull. Earthq. Res. Inst. Tokyo,* **43** : 237-239.

Chaudhury, H.M. *et al.*, 1970, *Proc. Fourth. Symp. Earthq. Engng.*, Roorkee : 382-388.

Gibowicz, S.J., 1973, *Bull. Seismol. Soc. Am.*, **63** : 517-528.

Hukku, H.M., 1966, *Proc. 3rd Symp. Earthq. Engng.*, Roorkee.

Krishnaswamy, V./S., 1962, *Proc. 2nd Sy mp. Earth q. Engng.*, Roorkee : 411-422.

Mehta, P.N. *et al.*, 1970, *Proc. 4th. Symp. Earthq. Engng.*, Roorkee : 411-418.

Mogi, K., 1968, *Bull. Earthq. Res. Inst.*, **46** : 53-74.

Nasu, N.F. *et al.*, 1931, *Bull Earth. Inst.*, **9**: 22-35.

Oldham, T., 1883, *Memo. geol. Surv. India.*, **XIX**, 1-4, 163-210.

Richter, C.F., 1935, *Bull. seismol. Soc. Am.*, **25** : 1-32.

Srivastava, L.S. and Somayajulu, J.G., 1966, *3rd. Symp. Earthq. Engng.*, Roorkee : 417-422.

Tandon, A.N. and Chatterjee, S.N., 1968, *Indian J. Met. Geophys.*, **19** : 273-280.